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BIOLOGICAL AND ENVIRONMENTAL EFFECTS OF NUCLEAR WAR

SUMMARY-ANALYSIS OF HEARINGS

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ERRATUM

On page 8, beginning at the 12th line from the bottom, the paragraph should read:

"Probably the most significant finding presented to the subcommittee was that civil defense preparedness could reduce the fatalities of the assumed attack on the United States from approximately 25 percent of the population to about 3 percent. The provision of shielding against radiation effects would at the same time protect against blast and thermal effects for the vast majority of the population."

44501°—59

The resources of the Atomic Energy Commission, its personnel and unclassified publications, were made available by Chairman McCone and were of great value to the subcommittee.

The subcommittee also utilized a mass of unclassified data furnished by other governmental and private sources on the effects of radiation. A special mention of appreciation is due Dr. Paul Tompkins and his associates of the U.S. Naval Radiological Defense Laboratory. Much of the basic data presented at the hearings was derived from the work of the USNRDL, and Dr. Tompkins and his staff consulted freely with the subcommittee throughout the hearings and during the preparation of this report.

The witnesses presenting testimony were selected on the basis of their competence and experience in the different fields of nuclear phenomena, with particular emphasis on nuclear weapons effects.

In the biomedical field the subcommittee received testimony from those scientists and technical personnel having the broadest experience in laboratory work on test animals and in the treatment of human beings exposed to radiation at Hiroshima and Nagasaki and in the accidental contamination of the Marshall Islands.

For the consideration of structural damage from blast and fire and of other weapons effects, outstanding authorities presented their findings and the latest available scientific data.

The weather patterns and other meteorological data for the date of the hypothetical attack were established by experts of the U.S. Weather Bureau, supported by their worldwide organization.

The reader is encouraged to examine the full testimony and supporting data of each witness in the printed record of the hearings. In this report the subcommittee has endeavored to present a faithful and concise summary of the data and to highlight the key issues for the convenience of the public and the Congress. Naturally, these data and issues are more completely set forth in the verbatim hearing record.

II. Summary

THE HYPOTHETICAL ATTACK

The hypothetical attack set forth by the subcommittee assumed that 263 nuclear weapons in 1, 2, 3, 8, and 10 megaton sizes with a total yield of 1,446 megatons [5] were detonated on 224 targets within the United States. An additional 2,500 megatons were assumed to have been detonated elsewhere in the Northern Hemisphere in attacks on overseas U.S. bases and in retaliation against the aggressor homeland. All weapons were arbitrarily designated as having a yield of 50 percent fission and 50 percent fusion. A weapon with 50 percent fission yield is one in which 50 percent of the total energy (yield) is derived from the fission process. Nuclear fission refers to the splitting of heavy atoms such as uranium and is the primary source of contamination of radioactive fallout particles.

[5] A 1-megaton bomb has the same explosive energy release as 1 million tons of TNT. The Hiroshima bomb yield was estimated at 20,000 tons of TNT, or 20 kilotons.

CASUALTIES AND DAMAGE TO DWELLINGS

The expert testimony and supporting scientific data presented at the subcommittee hearings indicate that under present conditions such an attack would have cost the lives of approximately 50 million Americans, with some 20 million others sustaining serious injuries. More than one-fourth (11.8 million) of the dwellings in the United States would have been destroyed and nearly 10 million others would have been damaged. Some 13 million additional homes would have been severely contaminated by radioactive fallout. Altogether, approximately 50 percent of existing dwellings in the United States would have been destroyed or rendered unuseable for a period of several months.

Although the weapon detonations used in this exercise were designated as surface bursts, which would maximize the local radioactive fallout hazard, nearly 75 percent of the deaths would have resulted from the blast and thermal effects, combined with immediate radiation effects. Only 25 percent of all fatalities would have resulted from fallout. At the same time, more than half of the surviving injured would have radiation injuries.

Most of the damage sustained by dwellings would have resulted from the blast and thermal effects.

BIOLOGICAL EFFECTS

The three casualty-producing phenomena of nuclear weapons—blast, thermal, and radiation—occur in varying combinations, depending on proximity to the point of detonation. At close range one would encounter all three, including fallout radiation as well as immediate radiation from the fireball.

1. *Blast effects*

Blast produces primary effects resulting from the blast wave itself (lung damage, rupture of eardrums); secondary effects, resulting from flying fragments (loose debris, building materials) propelled with great force by the blast wave; and tertiary effects, resulting from the body itself being thrown violently by the blast wave. In addition, miscellaneous injuries will result from conditions created by the blast on surrounding objects (e.g., broken gas mains, downed power lines).

Approximately 95 percent of the blast casualties produced by a 10-megaton weapon will result from the secondary and tertiary blast effects. For this size weapon the secondary effects are important to a distance of 11 miles; the tertiary effects can occur to distances of from 7 to 16 miles.

2. *Thermal effects*

Thermal effects consist of fires caused by direct ignition of combustible materials, skin burns on exposed portions of the body, and temporary or permanent blindness from the intense light of the fireball.

In the hypothetical attack situation posed by the subcommittee, thermal effects, including the hazard of mass fires ("fire storms"), could extend over large areas, in some cases up to distances of 20 to 25 miles from the point of detonation.

3. Radiation effects

The most severe form of radiation injury, under conditions of nuclear war, would be that resulting from severe exposure to the primary radiation "flash" (close to ground zero) or that attending whole body exposure to close-in fallout during the first day or so. However, severe irradiation could occur as a result of prolonged exposure to local fallout even after the first day unless survivors were provided with adequate shelter protection. Direct contamination of the skin with fallout debris could produce painful "beta burns" due to the action of beta rays irradiating the skin and outer layers of the body surface. In addition, there is an internal hazard of radioactive material which gains entry into the body through inhalation, ingestion, or through open wounds.

(1) *Acute effects.*—Instantaneous radiation doses of 5,000 roentgens or greater immediately produce symptoms of shock; death occurs within hours.

Radiation doses of 1,000 to 5,000 roentgens produce nausea and vomiting, fever and general fatigue within a few hours. Temporary recovery is followed within 1 or 2 weeks by reappearance of symptoms and probable death.

Exposure to doses of 200 to 1,000 roentgens causes nausea and vomiting within a few hours and in the period of from 2 to 4 weeks after exposure major changes will occur in the composition of the blood, rendering the body particularly susceptible to infections during this time. Approximately one-half of those exposed at the level of 450 to 700 roentgens would be expected to recover if not subjected to additional physical stress or radiation. The other one-half would die within 2 to 4 months. Probability of recovery increases greatly at levels below 450 roentgens.

Radiation doses of 200 roentgens or less will produce only mild symptoms of nausea and vomiting. Changes in the blood may occur later, but individuals so exposed usually will not require hospitalization.

(2) *Effects of protracted radiation.*—Higher radiation doses can be tolerated by the body without developing symptoms of acute radiation illness if exposure is spread over a longer period of time. Approximately 90 percent biological recovery can occur with continued or repeated exposures, but the remaining 10 percent nonrepairable injury may produce late effects, such as cancer, over a period 20 years or more.

When only a part of the body is exposed, the ability to recover is greatly increased. For example, the exposure of a person's legs alone to 500 roentgens of radiation would not result in a lethal dose.

The probability of increasing the incidence of leukemia and other types of cancer is considered proportional to the average total radiation dose sustained by the surviving population. Potential deaths from this cause are estimated as about 2 percent of the deaths attributable to acute radiation injury. These deaths will be spread out over a period of decades since it is a characteristic of radiation-induced cancer to be long delayed after incidence of injury.

(3) *Skin burns from fallout.*—Skin burns can be caused by beta rays from the fallout particles coming in direct contact with the skin. However, very large doses of beta radiation are required to produce severe burns, and the particles may be removed from the skin by good

fallout decontamination would be required to reduce the strontium 90 content of the soil to a level acceptable for production of some food crops and milk.

3. Long-term environmental effects

Although much remains to be learned about the long-range impact of a nuclear war on "the balance of nature," the concensus of the testimony was that, despite the severe shock, life would continue and full ecological recovery would eventually occur.

ADDITIONAL DATA ON RADIOACTIVE FALLOUT

Several additional factors presented to the subcommittee with respect to radioactive fallout are considered highly important.

(1) The worldwide strontium 90 fallout resulting from the assumed attack would not pose a major survival problem in countries not attacked. The level of strontium 90 deposited from long-term fallout would be higher than the maximum permissible concentration recommended for the population as a whole on a peacetime standard, but lower than the recommended maximum permissible occupational dose under controlled conditions.

(2) The actual release of gamma radiation energy from fission products differs significantly from that represented by the standard formula ($t^{-1.2}$ rule) contained in the official Government publication, "The Effects of Nuclear Weapons." New calculations indicate that early dose rates will be of greater intensity than previously believed and that over a long period of time the rate of decline will be more rapid. While the problem of immediate survival in a nuclear war is thus increased, the problem of long-term recovery is reduced.

(3) Local fallout is significantly affected by wind and weather. Actual fallout contours will differ markedly from the idealized cigar-shaped patterns normally used as a basis of estimating fallout effects. Moreover, peak fallout intensities will almost never occur at or near the point of weapon detonation. For example, the maximum fallout intensity for a weapon of a 5- to 10-megaton yield may appear at a distance as great as 60 to 70 miles from the point of detonation.

SURVIVAL MEASURES

Probably the most significant finding presented to the subcommittee was that civil defense preparedness could reduce the casualties of the assumed attack on the United States from approximately 30 percent of the population to about 3 percent. The provision of shielding against radiation effects would at the same time protect against blast and thermal effects for the vast majority of the population.

The cost of providing high-performance shelter protection for 200 million people was estimated at between $5 billion and $20 billion.

The main conclusion presented to the subcommittee was that the country must have a national radiological defense system if the Nation is to withstand and recover from an attack of the scale which is possible in an all-out nuclear war.

STRATEGIC IMPLICATIONS

In the course of the hearings the subcommittee received testimony on some of the strategic implications of the scientific data presented. A digest of this testimony and related panel commentary is included in an addendum to the report.

III. The Attack Pattern and Basic Assumptions

The attack pattern and basic assumptions established by the subcommittee for consideration in these hearings reflected an attack against the United States on a limited scale. That is, the number and total megatonnage of weapons employed were less than the maximum which a potential enemy is capable of launching against the United States.

At the same time, the pattern of the hypothetical attack was designed for a greater dispersion of weapons than would obtain in a so-called "limited" attack directed only against U.S. strategic offensive forces.

Although no classified information was utilized and the attack pattern was developed without assistance from any governmental agency, the realism of the assumptions was confirmed at the request of the subcommittee by competent military experts.

The targets in the United States were selected on the basis of criteria used by the Office of Civil and Defense Mobilization in its unclassified civil defense exercises and from published lists of military bases and Atomic Energy Commission installations.

The hypothetical attack consisted of 263 nuclear weapons delivered on 224 targets in the United States. The total megatonnage (millions of tons of TNT explosive equivalent) of the attack was 1,446, consisting of weapons ranging in size from 1 megaton to 10 megatons, as indicated in the following table:

Table III—1.—*Weight of the attack*

Size of weapon	Number used	Weight of attack (megatons)
10 megatons	60	600
8 megatons	74	592
3 megatons	44	132
2 megatons	37	74
1 megaton	48	48
Total	263	1,446

Of the 224 targets, 71 were large industrial and population centers officially designated by the OCDM as "Critical Target Areas." Military installations constituted an additional 132 targets and the remaining 21 targets were Atomic Energy Commission facilities.

The following table indicates the dispersion of weapons among the several classes of targets:

TABLE III—2.—*Targets of the attack*

Type of target	Number	Number of weapons	Weight (megatons)
Air Force installations	111	111	645
Critical target areas	71	110	567
AEC installations	21	21	168
Army installations	12	12	24
Navy installations	5	5	28
Marine Corps installations	4	4	14
Total	224	263	1,446

All weapons were arbitrarily designated as 50 percent fission and 50 percent fusion weapons detonated at ground level, that is, with the fireball touching the earth's surface. Each weapon was assumed to have been detonated at or near its specified target by using a standard statistical method for random bombing errors.

The total of 1,446 megatons was considered the yield of the weapons detonated, not the gross attack which the aggressor force might have launched initially, and no attempt was made to "war game" the overall problem of weapon delivery, interception, and retaliation.

For purposes of computing worldwide fallout and its effects for a period of 5 years after the attack, again without war gaming, it was assumed that 2,500 megatons of weapons were detonated on areas of the Northern Hemisphere outside the continental United States, representing the net result of attacks on U.S. overseas bases and U.S. retaliatory strikes against the aggressor homeland.

The general distribution of targets in the United States is illustrated on the map in figure III—1.

The time of the hypothetical attack was set at 12 noon Greenwich time (7 a.m. eastern standard time) on a typical October day, which assumes completed harvest and storage of food crops in the aggressor homeland. The actual weather conditions used in plotting fallout patterns and determining the effects of meteorological factors were those recorded for October 17, 1958, a typical fall day. It was necessary to select a particular day in the past in order to provide the weather data for accurate calculations.

IV. BASIC EFFECTS OF WEAPONS EMPLOYED

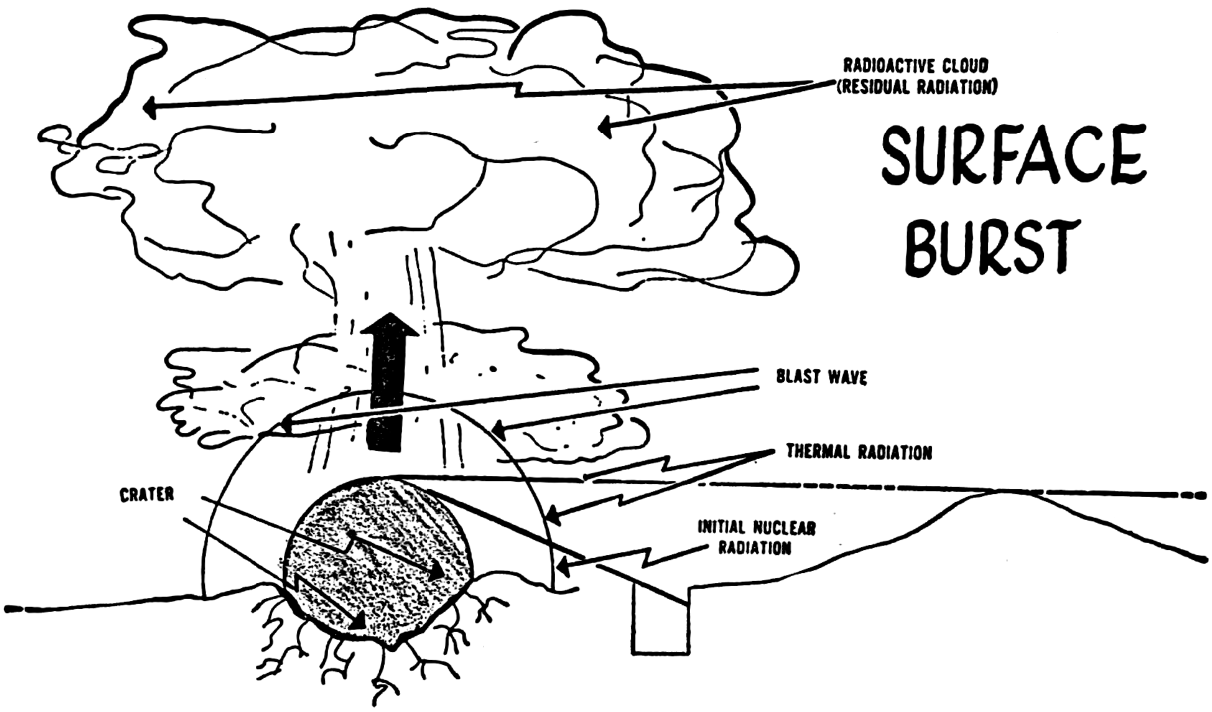
As indicated above, the weapons employed in the hypothetical attack assumptions consisted of 50 percent fission and 50 percent fusion weapons ranging in size from 1 to 10 megatons, all detonated at ground level. The following data concerning the basic effects of these weapons were presented at the subcommittee hearings. Later sections of this report will discuss the biological and environmental effects of these weapons in greater detail.

1. *Partition of energy in a nuclear explosion*

About 35 percent of the total energy of a nuclear explosion is given off as radiant thermal energy or heat, in much the same way as the sun radiates heat. Another 50 percent of the bomb energy is contained in the blast wave that travels several times the speed of sound. About

Surface burst.—A surface burst is one in which the fireball intersects the surface. (See fig. IV–2.) Local fallout is maximized in a surface burst. A crater is formed in the vicinity of the burst and is highly radioactive. The range of thermal and nuclear radiation effects is reduced by the natural shielding of hills and buildings.

FIGURE IV–2



3. Nuclear weapons effects on materials and structures

(1) *Blast.*—Multistory brick apartment houses are quite vulnerable to the blast wave. All such structures would be destroyed within a radius of 7 miles from ground zero for a 10-megaton weapon and within 3 miles for a 1-megaton burst. Thus, a factor of 10 in yield changes the radius of destruction by about a factor of 2.

A well-constructed wood-frame house completely collapses within 9 miles from a 10-megaton surface burst and within 4 miles of a 1-megaton burst.

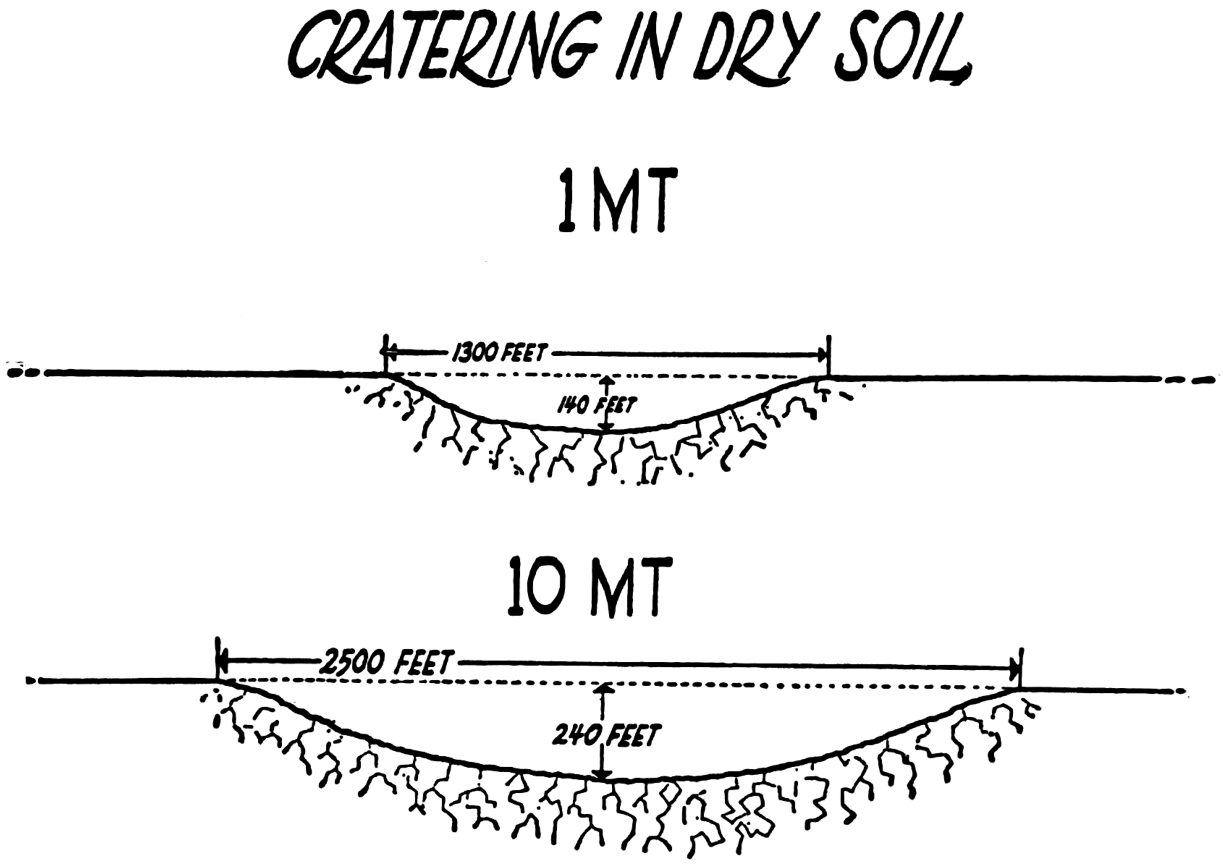
(2) *Thermal.*—Fires can be started by the ignition of light kindling materials anywhere within about 9 miles from a 1-megaton burst and within 25 miles from a 10-megaton burst. Thus, the presence of light kindling materials, such as trash, paper, and unpainted wood in a residential area will probably result in widespread fires.

(3) *Nuclear radiation.*—Initial nuclear radiation and fallout have very little effect on most inanimate materials. However, fallout can deny the use of inanimate objects to man until they are decontaminated by removing the radioactive particles.

(4) *Crater.*—Such hard structures as underground installations are quite invulnerable to the other effects, but can be destroyed by the cratering effect of a surface burst. (See fig. IV–3.) The damage would not be confined to just the crater dimensions, but would extend also into the rupture zone, a region having a diameter about twice the

crater diameter. Almost no structure nor its occupants would survive within this region.

FIGURE IV–3



4. Nuclear weapons effects on man

(1) *Blast.*—Blast overpressure in itself is not a significant casualty agent. However, the secondary effects and injury caused by crumbling buildings, flying debris, and man himself being thrown about, are certainly significant. Extensive blast injury can be expected at distances at which brick apartment houses collapse (7 miles from 10 megatons and 3 miles from 1 megaton). Extensive window breakage and flying glass would also occur at these and somewhat greater distances.

(2) *Thermal.*—Second degree burns of the hands or face will incapacitate an individual. For a 1-megation burst, an exposed person 9 miles from ground zero on a clear day can be expected to receive second degree burns on the exposed skin. For a 10-megaton burst, this range would be less than three times as great, or about 25 miles.

(3) *Initial radiation.*—Nuclear radiation is measured in units of rem (roentgen equivalent mammal). A rem is defined as the amount of radiation of any type required to produce a biological effect equivalent to that of 1 roentgen of X-ray. Two hundred rem will cause vomiting and nausea in 50 percent of a group of people by the end of the first day, but none or very few would be expected to die. A dose of 450 rem would cause vomiting and nausea in all of a group by the end of the first day, and according to the official handbook entitled "The Effects of Nuclear Weapons," [8] about half of the people so exposed would be expected to die within 30 days. This is termed the

[8] "The Effects of Nuclear Weapons," prepared by the U.S. Department of Defense and published by the U.S. Atomic Energy Commission, Washington: U.S. Government Printing Office, 1957.

SUMMARY OF EFFECTS FOR 1-MEGATON AND 10-MEGATON NUCLEAR WEAPONS

Blast, which is primarily a damaging agent to inanimate objects such as buildings, produces flying debris which is a hazard to man. The cratering effects result in the destruction of even deep underground structures.

Thermal radiation damages both humans and combustible structures and materials.

Nuclear radiation, including both the initial and residual fallout are primarily hazards to man and animals.

The distances and areas covered by various effects are contained in the following table:

TABLE IV–1.—*Summary of effects of the assumed nuclear weapons 1 to 10 megatons*

	1 megaton	10 megatons
A. Inanimate objects:		
1. Crater (dry soil)	Radius, 650 feet; depth, 140 feet.	Radius, 1,250 feet; depth, 240 feet.
2. Brick apartment houses collapse.	Radius, 3 miles	Radius, 7 miles.
3. Ignition of light kindling materials.	Radius, 9 miles	Radius, 25 miles.
B. Man:		
1. Blast injury (flying debris)	Radius, 3 miles; area, 28 square miles.	Radius, 7 miles; area, 150 square miles.
2. 2d degree burns on bare skin	Radius, 9 miles; area, 250 square miles.	Radius, 25 miles; area, 2,000 square miles.
3. Initial nuclear radiation (700 rem).	Radius, 1.5 miles; area, 7 square miles.	Radius, 2 miles; area, 12.5 square miles.
4. Fallout, 15-knot winds (450 rem in 48 hours, no shielding).	40 miles downwind; 5 miles crosswind; area, 200 square miles.	150 miles downwind; 25 miles crosswind; area, 2,500 square miles.

V. RADIOACTIVE FALLOUT PATTERNS, PHYSICAL DAMAGE AND CASUALTIES IN THE UNITED STATES

Based on the specific attack assumptions developed by the subcommittee, the Office of Civil and Defense Mobilization prepared a damage assessment with respect to blast, thermal, and fallout effects on dwellings and people during the period of 90 days following the attack.

While the primary effects of nuclear explosions may claim the greatest number of victims, the threat of persisting radioactivity poses the greatest hazard to survivors. It was for this reason that the subcommittee devoted much of its investigation to the problem of radioactive fallout.

FALLOUT PATTERNS

The fallout situation plotted by the OCDM is depicted on the maps reproduced in figures V–1, 2, 3, 4 and 5 showing conditions at the postattack time periods of 1 hour, 7 hours, 2 days, 2 weeks, and 3 months.

These maps show the progression of fallout across the United States during the first 2 days postattack and then indicate its subsequent retreat as radiation decay begins to predominate over further deposition of fallout. At 1 hour post-attack less than 10 percent of the country is affected by fallout but the dose rates are very high, exceeding 3,000 roentgens per hour in some areas. By 7 hours, approximately 30 percent of the national land area is covered by fallout intensities exceeding 1 roentgen per hour; and after 2 days 46 percent of the national land area is affected by intensities ranging from one-tenth roentgen per hour to greater than 30 roentgens per hour. Two weeks after the attack, as a result of radiation decay, only 15 percent of the national land area has fallout intensities exceeding one-tenth roentgen per hour and after 3 months only 5.8 percent of the area is affected by this intensity.

Two important factors concerning these fallout data require special attention. First, it is important to distinguish between the radiation dose rates, indicated here, and total dose accumulation, that is, the total dose which an unsheltered person would receive in a given period of time at a specified geographic location. Secondly, the stated dose rates as computed by OCDM are based on the $t^{-1.2}$ decay principle, which is at variance with later findings of the U.S. Naval Radiological Defense Laboratory.

The $t^{-1.2}$ rule, which long has been accepted by the scientific community, simply means that in general the radiation intensity existing 1 hour after a nuclear explosion will decline by a factor of 10 for every sevenfold increase in time. That is, if the 1-hour postattack dose rate is 3,000 roentgens per hour, 7 hours after the explosion the rate will be 300 roentgens per hour. Forty-nine (7×7) hours after the explosion the rate will be 30 roentgens per hour. At 343 (7×7×7) hours after the explosion the rate will be 3 roentgens per hour.

Although the NRDL data suggest a slower initial decline in dose rate, they indicate a more rapid decline after 1 year. However, whether one uses the $t^{-1.2}$ rule or the NRDL data, the requirement for population shielding in the period immediately following a possible attack remains substantially the same. A fuller discussion of the NRDL data is contained in a later section of this report, beginning at p. 28.

With respect to total radiation doses, data presented at the hearings indicate that in some sections of the country the hypothetical attack would have produced accumulated doses exceeding 12,000 roentgens during the first 3 months. As pointed out by OCDM witnesses, this means that persons who survived the initial impact of the attack in such highly contaminated areas would have to be moved to safer locations.

It should be noted that the official OCDM position with respect to the radiation hazards of a possible nuclear war is that fallout shelters should be prepared for the entire population of the United States. Although the fallout projections in figures V–1, 2, 3, 4, and 5 show some areas of the country to be free of fallout and others to be contaminated with extremely low radiation intensities, such areas cannot be accurately predicted in advance of a possible attack because of variables in such factors as target selection, aiming errors, weapon sizes and weather conditions.

DAMAGE SUSTAINED BY DWELLINGS

The blast damage sustained by dwellings in the United States as a result of the hypothetical attack is indicated in table V–1. Eleven million eight hundred thousand dwellings, or more than one-fourth of the dwellings in the United States, suffered damage to the extent that they would not be salvageable.

An additional 8.1 million dwellings suffered moderate damage and would have to be evacuated for major repairs; and 1.5 million dwellings suffered light damage. This totaled 21.4 million dwellings damaged.

TABLE V-1.—*Effects on dwelling*

	Units
Blast effects:	
Severe damage	11, 800, 000
Moderate damage	8, 100, 000
Light damage	1, 500, 000
Fallout effects:	
Greater than—	
3,000 roentgens per hour	500, 000
1,000 to 3,000 roentgens per hour	2, 100, 000
100 to 1,000 roentgens per hour	10, 400, 000
Less than 100 roentgens per hour	11, 700, 000

Outside the areas of blast and thermal damage, some 2,600,000 dwellings sustained radiation intensities exceeding 1,000 roentgens per hour and would have to be evacuated and abandoned for periods extending up to several months. An additional 10.4 million dwellings sustained radiation intensities varying between 100 and 1,000 roentgens per hour. With major decontamination effort most of these 10.4 million homes could be recovered by 60 days postattack.

In summary, almost 50 percent of existing dwellings in the United States were either severely damaged or contaminated by fallout to the extent that they would not be usable for at least several months postattack.

CASUALTIES

Based on 1950 census data, it was calculated that 19.7 million persons would have been killed the first day; 22.2 million additional persons would have been so badly injured that they would subsequently die of their injuries. There would have been approximately 17.2 million additional persons injured who could be expected to recover from the injuries received. Of those killed, 25 percent would have died from fallout and approximately 75 percent would have died as a result of blast and thermal injuries, combined to a great extent with radiation injuries.

Of the surviving injured, approximately 6.3 million would have blast and thermal injuries and 10.9 million would have radiation injuries.

Due to the population increase of approximately one-sixth since the 1950 census, it was noted that these casualty estimates might be increased by approximately 16 percent on a national basis. If this increase is included, the above casualty estimates would be changed to 22.8 million persons killed on the first day; 25.7 million additional persons fatally injured; and 19.9 million persons nonfatally injured. This increase, however, cannot be accurately applied to individual area estimates.

The charts which follow (tables V-2 and 3), again based on 1950 census data, show the numbers of fatalities and surviving injured by OCDM regional areas, by States, and within the 71 population and industrial centers included as targets in the hypothetical attack. It will be noted that of the total 19.7 million people killed on the first day, approximately 11.4 million were in the 12 largest metropolitan areas in the United States. The New York City area sustained the greatest loss with over 6 million dead or dying and over 2 million surviving injured. Seventy-five percent of the persons living in the Boston area were killed, and in Los Angeles fatalities amounted to 65 percent. In Chicago fatalities amounted to only 18 percent of the population, while in Baltimore they approached 80 percent.

With respect to radiation casualties, it is important to note that the OCDM estimates assumed that the population would take advantage of the fallout protection provided by existing buildings. The protection factors used in these estimates ranged from a reduction to one-half for those afforded the worst protection to a reduction to one two-hundredth for those afforded the best protection. It is possible that some groups of the population would have less protection than one-half reduction and some would have better protection than one two-hundredth reduction, but in the opinion of the OCDM the differences in the national totals would not be significant.

A factor of considerable significance, however, is that the above radiation casualty estimates are based on the $t^{-1.2}$ radiation decay rule, rather than on the most recent decay data developed by the Naval Radiological Defense Laboratory. Estimates based on the NRDL data, and subsequently presented by the OCDM at the request of Chairman Holifield, indicate that there would have been 5.1 million more fallout fatalities and 1.6 million more nonfatal fallout casualties than the $t^{-1.2}$ assumption indicated. The totals would then be 53.6 million fatalities and 20.5 million nonfatally injured.

It should also be noted in this connection that an upward revision of the estimated LD 50 rate (the radiation dose at which one-half those exposed would be expected to die), as suggested by some witnesses, would reduce the overall casualty estimates to some extent.

The subcommittee believes it is also important to note that almost 100 million of our people (56 percent of the population) would have survived this hypothetical attack without suffering blast, thermal, or serious fallout effects. Further, as pointed out by the OCDM, more than 96 million people in the United States do not live in or near likely target areas and could be expected to survive a nuclear attack merely through the provision of fallout shelter and a 2 weeks' supply of food and water.

The subcommittee recognizes that the long-range problems of a post-nuclear-war period would be extremely difficult, but this phase of recovery and rehabilitation was not within the scope of these particular hearings. A study of this aspect of national survival might well be explored by an appropriate committee of Congress.

nation on clay or loam, or in a metropolitan industrial complex such as a city is not known.

From table VI–1 it can be seen that the particle size of the debris descending at a distance of 8 miles from the point of detonation is expected to be relatively large, whereas the average size of the material depositing at 60 miles downwind is relatively smaller. By comparison, the material drawn into the stratosphere and which contributes to worldwide fallout probably has a particle size of the order of 0.02 millimeter. Attention is called to the fact that the distribution of radioactivity within the fallout particles themselves is quite irregular and that the bulk of the radioactivity associated with these particles is related to the particle size. It is significant that the largest particles contain the most radioactivity.

TABLE VI–1.—*Physical properties of land-surface burst fallout*

Properties of particles [1]	~8-mile downwind [2]	~60-mile downwind
General description	Melted, glassy solid containing air bubbles and mineral grains	
Range of diameters	~0.075 to 1.5 millimeters	~0.050 to 0.30 millimeter.
Predominant size	~0.35 millimeter in diameter	~0.10 millimeter in diameter.
Color	Transparent to opaque, pale green or yellow to brown or black	
Shape	Spherical to irregular	
Specific gravity	~1.4 to 2.6 gm/cm^3	
Distribution of radioactivity	Irregularly throughout	
Relation of radioactivity to size	$A \alpha D_{max}^{\sim 3}$ but with the range of A increasing with D_{max}	

[1] Based on properties of particles from kiloton bursts on silicate sand; all other information derived from megaton bursts on coral sand.

[2] ~: Approximately.

The chemical and radiochemical properties of the fallout material from a land-surface burst is summarized in the printed hearings. Less than 3 percent of the radioactivity associated with these large particles is soluble by leaching with water for several days. This implies that the radioactivity associated with these particles is not available for incorporation into plants and animals, at least for short periods of exposure to the elements. There is a significant list of radioactive isotopes which can be induced, either by neutron activation of materials within the weapon, or by activation of materials within the immediate environment, which under various conditions can contribute quite significantly to the quantity of gamma radiation associated with this fallout material. Testimony presented at the hearings indicated that the presence of such induced activities should be recognized and their presence ignored only after positive evaluation has indicated that it may be proper to do so.

Finally, it may be noted that under the conditions suggested in this exercise, as much as 90 to 95 percent of the fission products generated by the explosion could be found in the close-in or local fallout. This, of course, includes virtually all of the important gamma-emitting radioactive isotopes. However, due to the mechanism of formation as indicated in the preceding section, it is noted that only around 50 percent or less of the important isotopes strontium 90 and cesium 137 are found in the local fallout. Due to the mechanism of formation this fraction is highly variable but the general implication is that due to fractionation the gamma-emitting radioactive materials which can create a radiation threat from fallout under conditions of nuclear war are preferentially pulled down in the local fallout, whereas the long-lived isotopes which are significant in worldwide fallout and as possible sources of difficulty under conditions of the testing of nuclear weapons in times of peace, are preferentially distributed through the worldwide fallout. These fractions are also very highly variable and are quite sensitive to the precise conditions of the detonation. For surface bursts the standard estimate from the weapon-test program is to assume 80 percent of the total weapon debris deposits as close-in fallout, 15 percent appears as stratospheric fallout, and 5 percent remains in the troposphere.

The ability of gamma radiation to penetrate through solid materials such as would be found in the walls of structures is directly related to the energy of the radiation. Naturally, with a mixture as diverse as that of the fission mixture, the range of the energies from the gamma radiation is quite wide. It varies from as low as 0.01 Mev.[12] to as high as 2.5 Mev. It is, however, of considerable interest to see how the average energy of this complex mixture will change as a function of time. These data are shown in table VI–2.

TABLE VI–2.—*Radiation characteristics of land-surface burst fallout*

[In million electron volts]

Characteristics	8-mile downwind	60-mile downwind
Ionization decay rate: Average energy:		
1 hour	------------	1.0
2 hours	------------	0.95
½ day	------------	.60
1 day	------------	.40
1 week	0.25	.35
1 month	.45	.65
2 months	.55	.65
1 year	------------	.55

Arrival and deposition characteristics

The principal arrival and deposition characteristics of a land surface detonation are summarized in table VI–3. At a distance of 8 miles from a 5-megaton detonation, the first fallout material can be expected to start arriving about 15 minutes after the detonation, to reach its peak at about 1.5 hours, and to be essentially completed in 6 hours. The total mass of dirt would amount to several tons per square mile at this distance, and the major portion would carry no radioactive material at all. However, a portion would carry radioactive debris, and the gamma radiation dose rate would start increasing at the time the first material arrived.

The gamma radiation rate would continue to increase for about 2½ hours, at which time the rate of radioactive decay would become equal to the rate of replenishment and the dose rate would level off and start decreasing by the end of 4 hours. After 6 hours, when the fallout ceased, the dose rate would diminish with a rate characteristic of the mixture of radioactive species that was present at that point.

At a distance of 60 miles, the time sequence would be very much the same, but slower. Fallout material would start arriving at about 7 hours after the detonation. It would reach a peak at 13 to 14

[12] Mev.: A unit of energy expressed in millions of electron volts.

altitude. In the real case, as a result of the fact that the material is not in a perfect terrain but has a finite depth, the radiation intensity first increases with altitude and then decreases as the height of the point over the cleared area is increased.

(5) The ratio of observed to calculated radiation intensities has also been found to vary with time. It was reported that in at least one case for measurements made in the Pacific, a ratio of 0.45 was found at 11 hours, 0.66 between 100 and 200 hours, and 0.56 between 370 and 1,000 hours after the detonation.

(6) According to the testimony, the influence of vegetation and trees, which could elevate some of the fallout material above the surrounding ground level, is very small when compared to radiation emanating from material on the ground. Specific corrections to allow for the presence of vegetation are not currently incorporated in estimates of the radiation intensities generated at a point as the result of fallout deposition.

(7) When the fallout occurs over a community, a number of departures from the estimates for an infinite flat plane occur. Part of the fallout that would have been deposited on the ground is, instead, deposited on the roof. This has the effect of reducing the predicted intensity by placing the source a greater distance away from the point of concern near the ground and also results in interposing material in the building structure between the fallout and the point of concern. The resulting reduction in radiation intensity was estimated to be as little as a factor of 2 in light frame residential buildings of the 1-story design, to a factor of 10 to 20 in the basements of 2-story residential buildings made of heavy material such as brick. Testimony also indicated that moderately simple protective measures such as could be provided by a combination of tables and sandbags could reduce the radiation intensities by as much as a factor of 100 in such a basement.

(8) Due to the intense scattering of both the immediate gamma radiation and neutrons from air, there is very little protection afforded to one building because it is surrounded by others. The radiation protection from that portion of the radiation dose which might come from the immediate gamma and neutron radiation would be changed by less than 50 percent due to the presence of other structures.

VII. Biological Effects

INTRODUCTION

The three basic casualty producing phenomena of a nuclear attack are (1) blast, (2) thermal, and (3) radiation. In an analysis of the biological effects of these phenomena it is necessary that they be considered singly and collectively and from the standpoint of the direct/prompt and the indirect/delayed effects.

Although it is unlikely that thermal burns, primary and secondary blast injuries, and radiation injury would occur singly in an appreciable portion of the casualties in those areas suffering heavy structural damage from weapons of any of the sizes employed in this attack, these effects were treated separately in the hearings in order that expert testimony from specialists in each field could be received.

Wherever possible, witnesses who have actively participated in human experience studies, i. e., the Hiroshima and Nagasaki surveys, the Marshallese studies and the radiation accidents both in the United States and abroad were called.

In those areas where little or no human experience data exist, the most competent testimony, based upon extensive laboratory experimentation utilizing animals, was solicited.

BLAST EFFECTS

The biological effects of blast were considered in four categories:

(a) Primary blast effects which cause lung damage and rupture of the eardrums due to the direct effect of the pressure wave on the body. In terms of peak overpressure in pounds per square inch, nuclear weapons blasts with their relatively sustained overpressures are much more efficient producers of casualties by a factor of 10 or more than are equivalent high explosive blasts. Nevertheless, lung hemorrhage and broken eardrums were uncommon in Japan. With 1- to 10-megaton weapons lung damage would be restricted to from 2.5 to 5.5 miles, which is well within the zone of destruction of brick apartment houses (3 to 7 miles). Ruptured eardrums might occur farther out—4.5 to 7.7 miles. In other words, serious to fatal primary blast injury is unlikely to occur as an isolated event.

(b) Secondary blast effects due to flying fragments which become missiles created by the pressure wave. This pressure or blast wave would produce injurious effects by propelling loose debris, broken glass or ceramics, and building materials to a velocity high enough to penetrate the human body. This effect is important out to 5 miles from a 1-megaton surface detonation and 11 miles with a 10-megaton surface detonation.

(*c*) Tertiary effects resulting from the body itself being thrown violently by the pressure wave. Human beings may become missiles upon being picked up and hurled laterally by the blast wave. These injuries are similar to automobile and aircraft accidents, and can occur to distances of 3 to 5 miles from a 1-megaton surface detonation and 7 to 16 miles for a 10-megaton surface detonation.

(*d*) Miscellaneous injuries due to ground shock (broken legs), dust, fires created by destruction of buildings, power lines and gas mains.

It was estimated that about 5 percent of the hazard from a 10-megaton surface detonation could be related to casualties resulting directly from the pressure wave (primary effect), and that about 95 percent of the casualties would result from missiles (secondary effects) and displacement (tertiary effects). It was also pointed out that, based on "free field" effects (i.e., likened to conditions which would obtain on a perfectly flat surface) the combined effects (blast, thermal, and initial ionizing radiation) varied with weapon yield. However, the effects would be encountered in the following sequence and combinations as one moves away from the point of detonation:

	Fallout radiation	Thermal	Blast	Immediate radiation
Point of detonation	+	+	+	+
↓	+	+	+	−
Increasing distance from point of detonation	+	+	−	−
↓	+	−	−	−

estimates of the predicted acute effects on man can be based directly on experimental data.

SKIN BURNS FROM FALLOUT

The intensely radioactive fallout particles emit short-range beta radiations in addition to the penetrating gamma radiations. If fallout particles are lodged in direct contact with the skin, a skin burn can be created at that point. Doses in excess of 1,000 roentgens to the skin are required to produce severe burns. Good personal hygiene, by removing the fallout particles from the skin, can offset this effect. Beta burns, by creating open lesions, are easily infected. As a threat to survival, skin burns from fallout particles are much less important than the threat of whole-body gamma radiation under the exposure conditions of nuclear war. Pictures of actual skin burns on the Rongelap natives following the event of March 4, 1954, were displayed to the subcommittee during the hearings. It is significant to note that these burns were observed although the natives had been removed from the islands before a lethal dose of penetrating gamma radiation had accumulated. The testimony indicated that problems from this effect would become more significant during times of recovery when the threat to immediate survival had passed.

INHALATION HAZARD FROM FALLOUT

Little quantitative data is available on the inhalation hazard from fallout, but data from all field tests and on the Rongelap (Marshall Islanders) people as well as from inhalation experiments in animals all suggest that in a relatively heavy fallout field: (1) the dose to the lung is unimportant compared to the total body radiation from the fallout field itself, (2) the dose to the lung is less than to the gastrointestinal tract even in the absence of eating contaminated food, and (3) that the dose to the thyroid gland from the I^{131} (iodine) (because I^{131} concentrates there) could be the largest dose received by any single organ of the body, in the absence of shelter in some fallout exposure situations.

INGESTION HAZARD FROM FALLOUT

Ingestion of fallout debris could result in much larger internal radiation exposures than inhalation, yet still be of lesser concern than the external radiation for unshielded persons. During the critical weeks following the attack ingested fallout material would be almost entirely from surface contamination. The principal potential hazards from ingestion of fallout for several weeks after a nuclear detonation would be the exposure of the gastrointestinal tract itself and exposure to the thyroid gland from deposition of I^{131} therein.

Theoretical studies suggest that radiation doses to the adult thyroid may be two or more times greater than to the intestines from ingestion of fallout material during most of the critical period. However, a 1,000- to 2,000-roentgen dose to the intestines would threaten survival, whereas the adult thyroid can normally withstand tens of thousands of roentgens before serious effects occur. Children's thyroids are more sensitive and the chance of late cancer from irradiation would be

TABLE IX–1.—*Survival arithmetic*

[Heavy fallout area: 3,000 roentgens per hour at 1 hour]

	Roentgens
Dose during 1st year	12,000
Dose during 1st 2 weeks	[1] 10,000
Dose between 2 weeks and 1 year	[2] 2,000

Shelter shielding factor	Emergency dose	Reduction factor	Operational recovery dose
	Roentgens		*Roentgens*
10	1,000	10	200
100	100	100	20
1,000	10	1,000	2
10,000	1		

[1] Emergency phase: 10,000 roentgens.
[2] Operational recovery phase: 2,000 roentgens.

This table shows that for the fallout condition used—

(1) A shielding factor of 10 is inadequate since a radiation dose of 1,000 roentgens is lethal.[18]

(2) A shielding factor of more than 1,000 is not profitable since 10 roentgens is less than 10 percent of the dose required to cause direct casualties. This implies acceptance of the corresponding nonrecoverable biological effects.

(3) A shielding factor of 100 would be adequate if the initial fallout level corresponded to a standard intensity of 300 roentgens per hour at 1 hour instead of 3,000 roentgens per hour at 1 hour.

Different combinations of useful radiological defense systems which relate different combinations of shielding effectiveness, stay time in the shelter, reclamation effectiveness, and radioactive decay properties are summarized in table IX–2.

TABLE IX–2.—*Useful radiological defense systems*

[Heavy fallout area: 3,000 roetgens per hour at 1 hour]

System No.	Emergency phase countermeasures	Operational recovery phase countermeasures	Dose during 1st year (roentgens)
1	6-month shelter with 0.01 residual number	None	320
2	6-month shelter with 0.001 residual number	None	210
3	2-week shelter with 0.01 residul number	0.1 reclamation	300
4	2-week shelter with 0.001 residual number	do	210
5	2-week shelter with 0.01 residual number	0.01 reclamation	120
6	2-week shelter with 0.001 residual number	do	30

Other factors relating to a national system may be summarized as follows:

(1) The need for a formal radiological defense system disappears at fallout levels less than a standard intensity of 100 roentgens per hour at 1 hour. The protection afforded by existing buildings is generally adequate for this condition.

(2) Most buildings offering a shielding factor of 100 or more are located in metropolitan centers and will be vulnerable to the effects of blast and fire if that area is a target.

[18] A *shielding factor* of 10 is provided in the basement of some two-story homes. See "The Effects of Nuclear Weapons," p. 404. The corresponding *residual number* which relates the dose in the unprotected condition to the dose with the countermeasure is 0.1.

(3) Where such protection does exist, additional provisions for ventilation, food and sanitation would have to be made.

(4) Very good protection can be provided by underground shelters. The best information available is for a particular design based on a 24- by 48-foot ammunition-storage magazine [19] buried under 3 feet of earth. This shelter was occupied by technical personnel at Operation PLUMBOB [20] at a distance of somewhat less than 1 mile from a 17-kiloton detonation. A documentary film shown at the hearings gave an impressive demonstration of its effectiveness.

(5) The USNRDL shelter provides for 100 people at an estimated cost of $100 to $125 per person sheltered. It provides a shielding factor for radiation of 1,000 or more, and protection against blast at a level of 10 pounds per square inch. Protection against mass fires can also be provided.

(6) The USNRDL shelter can be designed for protection against a blast pressure of 35 pounds per square inch. Availability of such protection under conditions of the subcommittee's hypothetical attack could reduce the fatalities from approximately 25 percent of the U.S. population to about 3 percent. All of these would result from the immediate blast effects—no deaths from either thermal or nuclear radiation being anticipated under these conditions.

(7) The cost of providing protection for 200 million people at the levels prescribed by the higher performance defense system was estimated as between $5 billion and $20 billion, depending on the use made of existing facilities. This cost is almost entirely in the shelter phase, since reclamation competence is largely a matter of training and organization.

(8) The main conclusion presented to the subcommittee was that the country must have a national radiological defense system if the Nation is to withstand and recover from an attack of the scale which is possible in an all-out nuclear war.

In addition to data on group-type shelters, the subcommittee also received testimony on techniques of adapting present buildings for shelter purposes and proposals for individual family shelters.

Information bearing on these points may be summarized as follows:

(1) Techniques for estimating the degree of protection that can be obtained from existing buildings have recently been developed.

(2) On the first floor of a two-story wood building, the radiation was estimated to average about one-half of that outside. On the first floor of a brick building, it was one-seventh.

(3) Closing openings in basements with bricks or sandbags will reduce the radiation in the basement by a significant amount.

(4) Radiation dose rates inside fireplaces and behind masonry chimneys are lower than those in the center of the room.

(5) A heavy table covered with 7½ inches of concrete block and placed in the corner of a basement will reduce the radiation dose rate by a factor of 200 to 1,000 over that observed on the ground outside the structure.

(6) Prototype models of a combination transistorized portable radio and radiation detection unit were demonstrated at the hearings. This concept of a "citizen's instrument" is known as the "Banshee" because

[19] This is basically a prefabricated building of the type known as a quonset hut.

[20] This test was conducted by the U.S. Naval Radiological Defense Laboratory under the sponsorship of the Atomic Energy Commission.

force that can absorb an enemy blow and still strike back with adequate strength and, second, certain minimum nonmilitary protection for the civilian population.

TYPES OF DETERRENCE

It was also stated that even if the "balance of terror" theory were correct, the United States would still be faced with important strategic problems. As the witness pointed out, in 1914 and 1939, it was the British and the French who declared war on the Germans and not vice versa. It is difficult for Americans to realize that, under certain circumstances, neither the Soviets nor the Europeans might believe that the United States would come to the aid of Europe. In making this point, the witness asked the subcommittee to ponder a hypothetical situation in which American defenses were so weak and Soviet retaliatory forces so strong that if the United States responded to a Soviet ground attack on Europe the Soviet counterretaliation would kill all 177 million Americans. Under such conditions, the witness said, it would not be surprising if neither the Europeans nor the Soviets found the U.S. promise to come to the aid of Europe credible. But if it is true that the Soviets and the Europeans would not believe that we would honor our commitments to our allies if it meant 177 million American deaths, what level of casualties do they believe we would accept? It was stated that, to the extent that the Soviets believe we can keep our casualties to a level we would find acceptable, whatever that level may be, they will be deterred not only from attacking the United States directly, but also from very provocative aggressions, such as a ground attack on Europe. But, it was said, to the extent that they do not believe we can keep casualties to an acceptable level, the Soviets may feel safe in undertaking these extremely provocative military adventures.

In discussing this aspect of the strategic problem facing the United States, the witness distinguished between what he called Type I deterrence and Type II deterrence. Type I deterrence, which the British call "passive deterrence" on the assumption that it requires no act of will to initiate a response, is the deterrence of a direct attack. If the United States were directly attacked, its response would be automatic. Type II deterrence, which the British have called "active deterrence" is defined as the forces necessary to deter an enemy from engaging in military adventures short of a direct attack on the United States itself. There is a question as to how effective nuclear retaliatory forces would be as a Type II, "active" deterrent. In pondering this question, it must be assumed that before launching on such an extremely provocative adventure, the enemy would have alerted his own retaliatory forces and instituted protective measures for his population. By such precautionary measures, the Soviets, according to the witness, might limit casualties to 10 percent of its population and one-third of its wealth. This is just about what they suffered in World War II, from which they had recovered by 1951. If the Soviets believed that they could limit destruction to this extent and were also convinced that the United States had failed to take the measures that would similarly limit destruction in the United States, they might well feel free to launch an aggressive attack.

Put another way, the subcommittee was told, a very moderate shelter program, which would combine protection against fallout and some blast resistance, could reduce the expected casualties to approximately one-third of those who would die if there were no protection at all. A more extensive program, designed to protect persons in our urban areas, could reduce the overall fatalities of this attack from 25 percent of the population to approximately 3 percent.

Such measures were believed not to be terribly expensive. The subcommittee was told that the program of fallout shelters, which would go far toward saving the lives of the 60 percent of all Americans who do not live in or near target areas, is one which depends on simple tools and simple techniques. The lives of millions could be saved or lost by a simple choice. Thus, one eminent witness pointed out that on the basis of the 1954 thermonuclear detonation at Bikini, where the area of blast and thermal effects was perhaps 300 square miles (a circle with a radius of 9¾ miles), the total area of likely radiation casualties was approximately 7,000 square miles. Clearly, the subcommittee was told, it is the people in the intermediate 6,700 square miles about whom something could be done: "We can save them easily; we can lose them easily."

The burden of the testimony received on this point was that if such protective measures were taken, the impact of America's ability to survive a nuclear war would be so great that the likelihood of such a war would be vastly reduced. So long as the Soviets have the advantage of forewarning and can reduce their already low vulnerability through a comprehensive civil defense program, the United States will be at a marked disadvantage. Its firm foreign policy will be open to doubt and disbelief, and to possible blackmail.

Thus, it was suggested that our lack of a civil defense program could lead the Soviets to take a provocative step which we could not ignore, and a nuclear war would have started with no protection for the American people. Or, as a final paradox, the subcommittee was told, in a world of great tension the Soviets may be unable to believe that we would allow an aggressor to strike us first, which the theory of "massive retaliation" implies. The acceptance of such a military disadvantage as a basis for our national policy may seem foolish to them. They may therefore discount the sincerity of our position and expect instead that the United States actually intends to strike the first blow. A war which neither side wanted could thus break out because of our defensive weakness.